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NUTRIENT REMOVAL FROM ENRICHED WASTE EFFLUENT BY THE HYDROPONIC CULTURE OF COOL SEASON GRASSES

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Law, James P., Jr.

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From grass yield and analyses data, the amount of plant nutrient material removed by the grasses was small compared to the total quantity supplied. Further studies are suggested to determine economic factors and design parameters.

Abstractor: James P. Law, Jr.
Institution: Robert S. Kerr Water Research Center, SCR
~~FWQA, USDI,~~

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NUTRIENT REMOVAL FROM ENRICHED WASTE EFFLUENT BY THE HYDROPONIC CULTURE OF COOL SEASON GRASSES

by

James P. Law, Jr., Research Soil Scientist
Water Quality Control Research Program
Robert S. Kerr Water Research Center
South Central Region
Ada, Oklahoma

for the

FEDERAL WATER QUALITY ADMINISTRATION

DEPARTMENT OF THE INTERIOR

Program #16080
October, 1969

ABSTRACT

Grasses were grown in hydroponic culture tanks to evaluate their nutrient removal capabilities when supplied with secondary-treated sewage effluent as the sole source of plant nutrients. Statistical methods were employed to determine the effects of the grasses, flow rates, and seasons on nutrient removal.

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Key Words: Hydroponic culture, tertiary treatment, waste water treatment, Nutrient removal, cool season grasses, waste assimilative capacity.

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CONCLUSIONS

Grasses were grown in hydroponic culture tanks to evaluate their nutrient removal capabilities when supplied with secondary-treated sewage effluent. The effluent supplied was the sole source of plant nutrients. Chemical analyses of the sewage effluent supplied and of the outflow from each of six hydroponic tanks were performed weekly during the one-year study.

Two control tanks with no grass were maintained throughout the study, two tanks were planted with tall (Kentucky 31) fescue, and two were planted with perennial ryegrass. Two flow rates were maintained in each pair of tanks, approximating one-day and two-day detention times. Statistical methods were employed to determine the effects of the grasses, flow rates, and seasons on nutrient removal.

All six tanks were quite effective in reducing the concentrations of oxygen-demanding organic materials in the effluent. Total nitrogen content was reduced appreciably by the control tanks, but the grass tanks were significantly better at nitrogen removal. Total phosphorus concentrations were reduced only slightly by passage through the tanks. The fast flow rate tanks produced the greater yields, while the slow flow rate tanks were more effective in nutrient removals from the sewage effluent.

The fescue produced over 10 tons per acre dry weight yield and the ryegrass yield was about 7 tons per acre for the year. From the grass analyses, the amount of plant nutrient material removed by harvest was computed. The quantities actually removed by the grasses were rather small compared to the total quantity supplied. About 4 to 8 percent of the nitrogen supplied was accounted for in the grass harvested, while about 2 to 5 percent of phosphorus and 6 to 22 percent of the potassium were removed in the harvests.

RECOMMENDATIONS

The results of this study suggest several avenues that require further investigation before the method could be recommended as feasible. Studies on a much larger scale should be conducted to determine the economic factors of the method. Field studies comparing the hydroponic technique with normal spray irrigation of grassland would appear desirable.

The indications are that shallower gravel beds could be used. Optimum bed depth and dimensions need to be determined from future studies. The effluent from the Ada sewage treatment plant averages between four and six acre-feet per day. If beds were constructed one-foot deep and operated with a two-day detention time in support media with 40 percent void space, rough calculations quickly show that 20 to 30 acres of bed area would be required to handle the entire flow.

Additional studies should determine the most desirable grass species or combinations of species from a nutrient utilization standpoint. These should produce luxuriant growth in all seasons of the year for maximum nutrient uptake. Ryegrass proved undesirable in this study because of its dormancy during the summer months.

The results of this study showed poor performance with regard to total phosphorus removal. This suggests that a different type of support medium, such as crushed limestone, might be desirable. In this way, the phosphates might be complexed with calcium and thus removed from the effluent.

In general, the results indicated a relatively minor role played by the grasses in removing the nutrients supplied. A much closer look at the feasibility of the method in future studies is suggested.

INTRODUCTION

Hydroponics is defined as the growing of plants in nutrient solutions with or without an inert medium to provide mechanical support. It has become well established as a culture method for many different types of plants and is especially adapted to greenhouse operations where light, temperature, humidity, and atmosphere can be controlled. Under normal operations, solutions are prepared with the proper proportions of all required nutrients and are fed to the root systems of growing plants. The composition of these solutions may be varied to suit the nutrient requirements of different plant species and in most commercial operations this becomes a well-guarded trade secret.

Hydroponic culture is widely used by the floriculture industry and is gaining much popularity in the production of high-valued vegetable crops such as tomatoes. A recent news release in the Sunday Oklahoman reported a commercial operation in Edmond, Oklahoma, that utilizes two 4,000-square-foot greenhouses and expects a yield of 40,000 pounds of tomatoes during a 10-week fruiting season; and this during the months when no field production is possible in the area.

Another interesting report appeared in the Denver Post (1) which described several hydroponics enterprises in that area. Kelly-Clark, Inc., of Loveland produces tomatoes with the trade name, "Gourmato," at the rate of 1,000 pounds per week from three greenhouses. Three growers in Golden market 3,000 pounds of tomatoes per week. Smaller "sideline" operations at Sterling, Colorado Springs, and Craig each produce from 700 to 1,000 pounds of tomatoes per week. A dairy owner at Deer Trail grows 1,000 pounds of barley grass "green feed" daily for his herd of 40 cows. The Denver Zoo produces from 700 to 1,000 pounds of barley grass daily for feeding waterfowl; and at the Denver Federal Center, a unit of the U. S. Fish and Wildlife Service grows 500 pounds of oat grass per day for birds and game animals kept for research purposes.

The fact that many plants will grow and extract their nutrient requirements from solution inspired the interest in the present study. This was viewed as a potential method for the biological extraction of nutrient materials from municipal waste effluents that are now being released to many of our surface streams. The principal objectives of this preliminary study were to find the most suitable grasses for this culture method, their yield on a seasonal basis, and the amount of nutrients that could be removed by the process.

Need for Research

The Water Quality Act of 1965 required all States to establish water quality standards for their interstate and coastal waters. These standards are the plans established by governmental authority for water pollution control and abatement, and they required the States to make crucial decisions regarding the uses of their water resources, the quality of water

Estimates (4) of biochemical oxygen demand (BOD) discharges to streams from municipal outfalls paint another interesting picture From 1900 to 1930, BOD discharges increased from 1.5 to 3.5 billion pounds per year. In 1930, only 15 percent of municipal sewage received primary treatment and less than 6 percent secondary. During the 1930's, sewage treatment plant construction was accelerated and BOD discharges decreased slightly. A sharp increase during World War II and a levelling-off period which followed brought a peak of 4.5 billion pounds per year in 1958, followed by a slight decline to 4 billion pounds per year by 1965. Assuming that in the next 20-year period all municipal wastes will receive primary-secondary treatment, a minimum of 2.5 billion pounds per year can be reached by 1985. From that point on, a steady increase due to population growth will bring us again to the 4.5 billion pound level by the year 2000. Projections such as these strongly emphasize the fact that treatment above and beyond our present secondary treatment capabilities will be required in the foreseeable future.

Admittedly, the above analysis is on a gross scale, but it gives some indication of the magnitude of the nutrient problem and the trend expected in the years ahead. The direct result of nutrient discharges to our lakes and streams is a greatly accelerated rate of eutrophication (5). Those nutrient compounds that are not removed in waste treatment processes occur in the effluent discharges in the soluble, more readily available forms, mostly as nitrates and phosphates. Their presence, even at low concentrations, can stimulate prolific growths of algae and other aquatic vegetation. The death and decay of such vegetation then exerts an added oxygen demand on the water which may adversely affect fish and other aquatic life. After degradation, the nutrients are released back to the water in soluble form and the process re-cycles. The only alternative to the problem of induced eutrophication is to employ treatment methods and technology to further control the release of nutrient materials to our surface waters (5).

The hypothesis of this study proposed that higher plants could be grown either floating on lagoons or using a gravel-bed support in specially built structures for the removal of nutrient materials remaining in sewage waste effluents. The methods employed and the results obtained constitute the remainder of this report.

to support these uses, and specific plans for achieving such levels of quality. The purpose of the program is to enhance the quality and value of the nation's waters and to protect the quality of clean water. These standards are the blueprints for an effective clean water program. The Federal Water Pollution Control Administration (FWPCA) set forth guidelines (2) to assist the States in establishing acceptable water quality standards and implementation plans. Those guidelines clearly established that water quality standards should be designed to "enhance the quality of water." They further stated that the implementation plan "...should include consideration of all relevant pollutional sources, such as municipal and industrial wastes, cooling water discharges, irrigation return flows, and combined sewer overflows." The result of these policy statements is that standards and implementation plans which have been approved call for secondary treatment of municipal wastes and equivalent levels of treatment for industrial wastes (3).

Even though the present state of technology is such that adequate treatment can be given to municipal wastes, many of the smaller municipalities simply are not in a position that allows them to employ the most modern treatment methods; and little imagination is required to envision the day when secondary treatment will not be acceptable in many cases. New and fresh approaches to waste treatment problems are called for. The hydroponic culture of higher plants to extract nutrient materials from waste effluent was viewed in this light. To our knowledge, no prior investigation of this nature has been carried out. These considerations prompted the present study as a preliminary step in meeting this need.

The Nutrient Problem

One of the most serious water pollution problems we face is the release of nutrient compounds of nitrogen and phosphorus to our waterways. Sewage treatment processes have been primarily designed to reduce the suspended, organic, oxygen-demanding materials. Efficiently operated secondary treatment plants remove about 90 percent of these materials, about 90 percent of the bacteria, 50 percent of the total nitrogen, 20 to 40 percent of the phosphorus, and only about 5 percent of the total dissolved matter. Weinberger *et al*. (4) show that only a very small fraction of river basins in the United States have complete secondary treatment of all municipal discharges, while a somewhat larger percentage of river basins have more than 90 percent of such discharges with complete treatment. They estimated the total nitrogen and phosphorus discharges to surface streams since 1900 with projections to the year 2000. According to their estimates, in 1900 there were about 200 million pounds per year of total nitrogen (as N) being discharged to U. S. streams. By 1965, this had grown to 1.2 billion pounds per year and an increase to 2.2 billion pounds per year is expected by 2000. Phosphorus discharges were estimated at about 20 million pounds per year (as P) in 1900. In 1965, the estimate was 250 million pounds per year and by 2000 the prediction is something over 500 million pounds per year. The expected increase in secondary treatment facilities beyond 1965 accounts for a slight decrease in the slope of these projected curves.

EXPERIMENTAL PLAN

The study was carried out in six large metal tanks constructed for the purpose. The tanks were built of galvanized metal and were 20 feet long, 3 feet wide, and 18 inches deep. Fittings were provided at the inlet and outlet ends and located near the bottom on each tank. Distribution manifolds were fitted horizontally inside the inlet and outlet ends of each tank to aid in better distribution of the fluid flow. Clean pea gravel was used as the inert support medium to a depth of 14 to 15 inches in each tank. A 2-inch layer of coarse concrete sand was placed on top of the gravel bed, and the grasses were planted in the moist sand layer. The liquid level was adjusted to the top of the pea gravel layer and maintained constant by a standpipe overflow at the outlet end.

An overhead tank supplied a constant head pressure of about 4 feet to the manifold and supply lines leading to each tank. A schematic drawing of the elevation plan is shown in Figure 1. The complete flow diagram from the overhead tank through the six tanks is represented in Figure 2. Two tanks were operated with no grass to serve as controls. Tall (Kentucky 31) fescue sprigs were planted in tanks 3 and 4, and perennial ryegrass seed were planted in tanks 5 and 6. Rows were planted on 6-inch centers, and the fescue sprigs were spaced 4 to 6 inches apart in the rows. These two grasses were selected on the basis of a study reported by Eby (6) in which several pasture grasses were successfully grown in animal wastes by hydroponic culture in the greenhouse.

The experimental design was such that factorial analysis could be employed to evaluate the effect of two flow rates and four seasons on the nutrient removal efficiency of the two grasses versus the control tanks. The flow rates were adjusted and maintained by means of a sediment chamber and orifice arrangement shown schematically in Figure 3. Two flow rates were employed to give approximately a one-day detention time (fast rate) and a two-day detention time (slow rate) in each of the pairs of tanks--control, fescue, and ryegrass (Fig. 2). Thus, the principal variables of the study were flow rate, grass species, and season. Factorial analysis of variances was employed to detect significant effects of these variables as well as interaction effects of the several combinations.

Study Site

The study was located at the Ada, Oklahoma, sewage treatment facility. The effluent from the final clarifier was fed to the grass tanks and was the sole source of plant nutrients. The treatment facility has a design capacity of 3.0 MGD and a daily average flow of 1.5 MGD. However, at peak flow periods during the day the flow capacity of the trickling filter is often exceeded causing short-circuiting. The basic facility consists of

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bar racks and screening mechanism with comminutor; grit chambers; primary settling basin; trickling filter with rotary distributor; and final clarifier. Sludge-handling equipment includes digesters and open sludge drying beds. Stormwater flow often causes dilution and wide variation in the chemical quality of the effluent. The effluent discharges to an intermittent stream of the Sandy Creek watershed, flowing eventually into the South Canadian River to the north.

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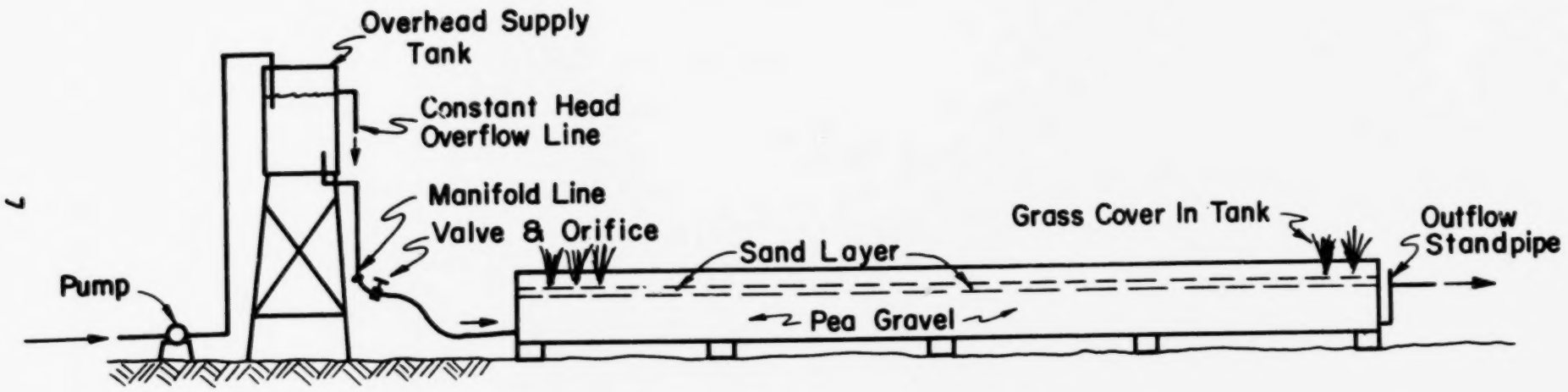

FIGURE 1 - SCHEMATIC OF ELEVATION PLAN

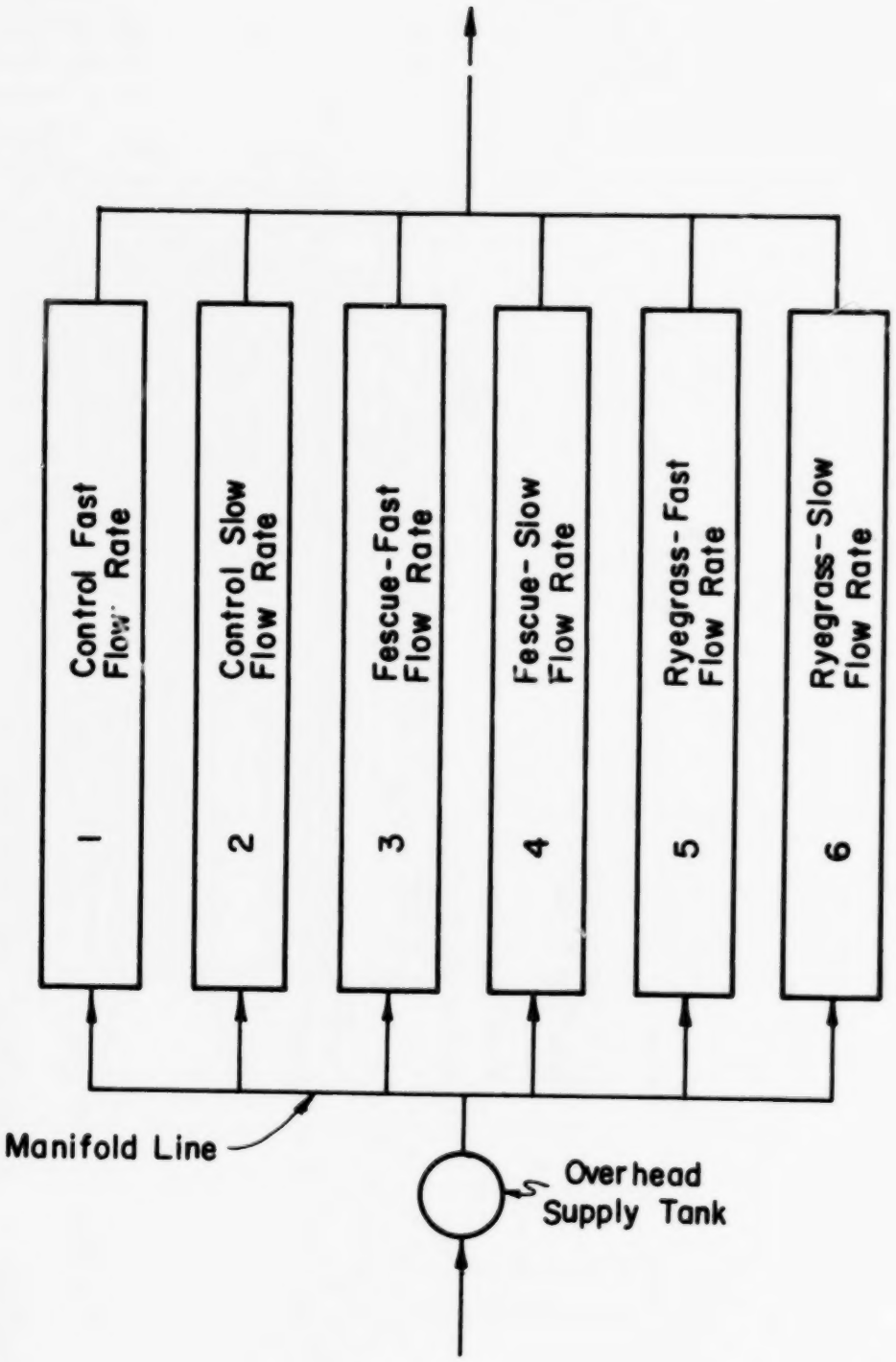

FIGURE 2 - FLOW DIAGRAM OF THE SIX TANKS

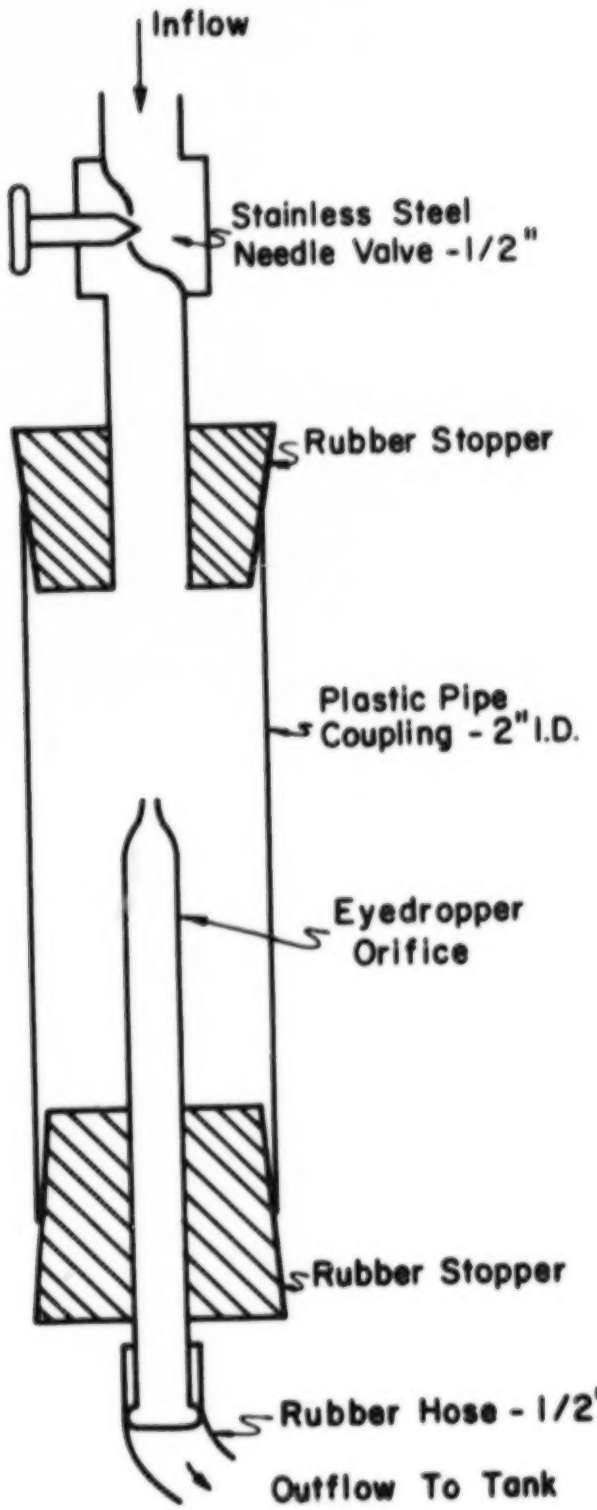

FIGURE 3 - SEDIMENT CHAMBER AND ORIFICE ARRANGEMENT FOR REGULATING FLOW TO TANKS

EXPERIMENTAL PROCEDURES

The tanks were installed and grasses planted in August 1967. A constant flow of effluent from the final clarifier at the Ada sewage treatment plant was maintained through the tanks while the grasses were being established. During this period, the sediment chamber-orifice arrangements were installed and adjusted for constant control of the two flow rates. In about two months the grasses were well established and showing lush fall growth. The sampling program was started in November 1967 and continued for 12 months.

Sampling Program

Inflow and outflow samples from all six tanks were collected on a weekly basis. Duplicate inflow samples were taken from the manifold line early in the week, usually Monday or Tuesday. Outflow samples from tanks 1, 3, and 5, the fast flow rate, were collected one day later; and from tanks 2, 4, and 6, the slow flow rate, two days later. This schedule was based on slug flow and theoretical detention times for the two flow rates. The following chemical analyses were performed on each sample collected: pH, electrical conductivity, chloride, sulfate, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic (nonvolatile) carbon, total and ortho phosphate, organic nitrogen, ammonia, nitrite, and nitrate nitrogen. In addition to these weekly determinations, the metallic cations, calcium, magnesium potassium, and sodium were determined on one set of samples each month. Chemical analytical methods were in accordance with APHA Standard Methods (7), ASTM Manual (8), and FWPCA Interim Methods (9).

Microbiological samples were collected periodically during the study to determine bacterial counts of both the inflow and outflow water. Counts of total coliform, fecal coliform, and fecal streptococci organisms were performed by the standard plate count method (7) employing the membrane filter technique.

Grass Samples

Harvest samples were collected and yields were calculated on each of the grass tanks several times during the year. Fall growth was harvested early in January 1968. The second harvest was made in late March and subsequent harvests were made monthly until hot summer weather slowed the growth rate. A total of eight harvests were made during the 12-month study period. Dried grass samples were retained for chemical analysis at the conclusion of the study. Crude protein, total nitrogen, phosphorus, potassium, calcium, and sodium were determined on each of the grass samples.

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RESULTS AND DISCUSSION

Effluent from the final clarifier was supplied to the hydroponic tanks. In order to evaluate the nutrient removal efficiencies of the hydroponic tanks, the chemical quality of the sewage treatment plant effluent supplied was determined at each weekly sampling period throughout the year. The quality characteristics of the effluent are summarized in Table 1 for the four seasons. The values reported are minimum, maximum, and mean for each parameter along with the annual weighted mean values. The organic and nutrient values appeared to be highest during the winter season and lowest during the summer. Inorganic parameters did not exhibit consistent seasonal variations. The principal factor affecting mineral salt concentration was dilution by rainfall and snow.

At the time the tanks were installed and initially filled with a 15-inch bed of pea gravel, the liquid capacity of the gravel bed was carefully determined. Each of the six tanks held 220 ±5 gallons when filled to the top of the gravel bed. This revealed an average value for the pore space of the gravel bed to be 41.3 percent of the total gravel volume. Flow rates were calculated on this basis in order to maintain theoretical detention times of one and two days. The fast flow rate (one-day detention) was calculated to be 578 ml/min while the slow flow rate (two-day detention) was 289 ml/min. Flow rates were measured daily during the 3-day sampling interval of each week. Some clogging of the flow orifice (Figure 3) occurred, and it became necessary to clean them on a regular weekly basis to ensure as nearly constant flows as possible. By this procedure, flow rates and detention times were maintained within a range of ±10 percent.

The major fertilizer nutrients, nitrogen, phosphorus, and potassium, were present in the sewage effluent at an approximate ratio of two parts N, one part P, and one part K. Converting these to the standard fertilizer designations gave approximate ratio values of three parts N, four parts P_2O_5, and two parts K_2O. The rate at which these were supplied to the hydroponic tanks was easily estimated from the flow rates.

Of the sixteen elements essential for plant nutrition, six are required in relatively large quantities and are referred to as the macronutrients (10). These are nitrogen, phosphorus, and potassium, the major fertilizer elements; and calcium, magnesium and sulfur. Using the annual weighted mean values of Table 1, estimates of the rate at which these six nutrients were supplied to the hydroponic tanks are shown in Table 2. Based on the tank area (57.3 sq. ft.) the values of Table 2 can be converted to pounds per acre per week by multiplying by 760. No attempt was made in this study to analyze for the micronutrients present in the sewage effluent supplied to the hydroponic tanks. The essential micronutrients used by higher plants are: iron, manganese, copper, zinc, boron, molybdenum, and chlorine (10).

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TABLE 1

CHARACTERISTICS OF SEWAGE TREATMENT PLANT EFFLUENT SUPPLIED TO THE HYDROPONIC TANKS

Parameter	Winter			Spring			Summer			Fall			Annual Weighted Mean
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	
pH, units (range)	6.9	7.7	-	7.1	7.7	-	7.2	7.7	-	7.3	7.7	-	6.9-7.7
Electrical Conductivity (EC), micromhos/cm	825	1435	1065	985	1250	1099	925	1100	1007	950	1150	1025	1045
Chemical Oxygen Demand (COD), mg/l	49	172	89.9	60	101	73.6	42	70	55.8	43	75	56.9	67.8
Biochemical Oxygen Demand (BOD), mg/l	32.2	69	47.6	16.4	65	28.3	18.4	49	31.1	17	43	28.7	31.8
Total Organic Carbon (TOC), mg/l	20	44.5	29.3	17.5	34.5	22.7	13.3	24	18.8	17.3	28.1	21.3	22.7
Total Phosphorus (T-P), mg/l as P	4.6	12.6	9.5	6.0	9.6	7.6	5.0	9.4	7.3	7.7	10.0	8.6	8.1
Organic Nitrogen (Org-N), mg/l as N	1.2	6.0	3.0	1.0	3.0	2.1	1.6	5.3	2.8	1.8	4.6	2.8	2.6
Ammonia Nitrogen (NH_3-N), mg/l as N	2.2	11.7	6.7	1.0	9.1	4.9	1.2	7.5	2.8	1.9	5.2	3.4	4.4
Nitrite Nitrogen (NO_2-N), mg/l as N	0.2	0.8	0.4	0.2	0.6	0.35	0.1	3.8	0.6	0.1	0.5	0.34	0.43
Nitrate Nitrogen (NO_3-N), mg/l as N	5.6	10.7	8.4	1.6	10.9	7.7	4.5	10.4	7.6	5.4	12.3	9.1	8.1
Total Nitrogen (T-N), mg/l as N	14.4	22.2	18.3	10.1	19.7	15.1	9.9	19.8	13.5	10.7	20.7	15.6	15.4
Chloride (Cl), mg/l	77	106	96.6	70	121	95.5	88	96	92	82	140	98.5	96.8
Sulfate (SO_4), mg/l	40	65	51.7	53	60	57	30	69	50	33	45	41	47.3
Calcium (Ca), mg/l	69	90	78.3	90	95	92.5	70	93	81	70	81	75	80.1
Magnesium (Mg), mg/l	28	39	35	30	36	33	27	36	31.5	35	36	35.7	34.3
Potassium (K), mg/l	8.0	10.5	9.3	7.4	8.0	7.7	6.4	9.0	7.7	6.8	8.9	7.9	8.5
Sodium (Na), mg/l	73	126	96.8	68	95	81.5	85	100	92.5	79	118	92.3	92.7

Note: (1) Milligrams per liter multiplied by 8.34×10^{-3} equals pounds per 1000 gallons.

(2) City water supply has electrical conductivity averaging about 625 micromhos/cm and a median pH of 7.5.

TABLE 2

ESTIMATED AVERAGE RATES OF SUPPLY OF MACRONUTRIENTS
TO THE HYDROPONIC TANKS

Macronutrient	Fast Flow Rate lb/week (lb/ac/wk)	Slow Flow Rate lb/week (lb/ac/wk)
Nitrogen (as N)	0.19 (144.4)	0.095 (72.2)
Phosphorus (as P)	0.10 (76.0)	0.05 (38.0)
(as P_2O_5)	0.23 (174.8)	0.115 (87.4)
Potassium (as K)	0.106 (80.56)	0.053 (40.28)
(as K_2O)	0.13 (98.8)	0.065 (49.4)
Calcium (as Ca)	1.00 (760.0)	0.50 (380.0)
Magnesium (as Mg)	0.44 (334.4)	0.22 (167.2)
Sulfur (as SO_4)	0.59 (448.4)	0.295 (224.20)
(as S)	0.195 (148.20)	0.097 (74.1)

Note: To convert pounds per week to pounds per acre per week, multiply by 760.

Characteristics of Effluent from Hydroponic Tanks

The quality of the effluent from each of the six hydroponic tanks has been summarized in Tables 3, 4, and 5. The seasonal values are means of the weekly data and the annual weighted mean is for the full year of the study. Comparison of the annual mean values with those of Table 1 shows that the tanks were not effective in reducing any of the inorganic parameters measured. Measurements of flow rates both in and out of the tanks were made periodically. Flow reductions due to evapotranspiration were found to range from not detectable to a maximum of about five percent and estimated to average about 3 percent. It was apparent that evaporation and transpiration from the tanks were insignificant compared to the volume flowing through, and no measurable increased concentration of salts was detectable. The small effect of evaporative processes could not be consistently detected even on individual sets of the weekly data.

Treatment Efficiencies

The greatest effect of passage through the hydroponic tanks was the reduction of the organic parameters and total nitrogen. All forms of nitrogen measured were appreciably reduced, but total nitrogen was taken as the indicator of nitrogen removal efficiencies. The mean removal

TABLE 3

MEAN CHARACTERISTICS OF EFFLUENT FROM THE CONTROL TANKS

Parameter	Tank 1. Fast Flow Rate					Tank 2. Slow Flow Rate				
	Winter	Spring	Summer	Fall	Annual Weighted Mean	Winter	Spring	Summer	Fall	Annual Weighted Mean
pH, units (range)	6.7-7.5	6.5-7.6	7.1-7.6	7.2-7.6	6.5-7.6	6.7-7.8	7.2-7.6	7.1-7.8	7.2-7.6	6.7-7.8
Electrical Conductivity (EC), micromhos/cm	998	1077	997	1046	1023	1043	1066	945	1010	1010
Chemical Oxygen Demand (COD), mg/l	34.2	34.0	33.0	25.8	31.6	37.8	41.6	34.1	27.2	34.9
Biochemical Oxygen Demand (BOD), mg/l	6.0	3.4	2.8	4.6	3.9	5.2	5.8	3.1	3.6	4.3
Total Organic Carbon (TOC), mg/l	13.4	13.4	11.1	10.4	11.9	12.7	13.7	10.5	10.9	11.9
Total Phosphorus (T-P), mg/l as P	8.8	7.4	7.3	8.6	8.1	8.7	7.8	6.2	8.0	7.7
Organic Nitrogen (Org-N), mg/l as N	1.2	1.0	1.3	1.1	1.2	1.2	1.3	0.8	0.9	1.0
Ammonia Nitrogen (NH_3-N), mg/l as N	5.3	3.9	0.9	1.4	2.9	5.4	3.8	0.4	0.8	2.6
Nitrite Nitrogen (NO_2-N), mg/l as N	<0.1	<0.1	<0.05	<0.05	<0.1	<0.1	<0.05	<0.1	<0.05	<0.1
Nitrate Nitrogen (NO_3-N), mg/l as N	3.7	3.4	1.3	3.4	2.9	3.1	2.1	0.6	3.3	2.3
Total Nitrogen (T-N), mg/l as N	10.1	8.4	3.5	5.8	7.0	9.7	7.2	1.7	5.0	5.9
Chloride (Cl), mg/l	74	109	97	114	99	98	101	88	108	98
Sulfate (SO_4), mg/l	48	67	43	40	45	50	64	45	41	46
Calcium (Ca), mg/l	74	97	76	76	79	71	98	82	72	79
Magnesium (Mg), mg/l	33	29	28	38	32	33	30	30	35	32
Potassium (K), mg/l	8.7	6.9	7.6	8.3	8.1	8.0	7.0	7.6	6.8	7.4
Sodium (Na), mg/l	92	92	94	103	95	91	77	94	98	91

Note: Milligrams per liter multiplied by 8.34×10^{-3} equals pounds per 1000 gallons.

TABLE 4

MEAN CHARACTERISTICS OF EFFLUENT FROM THE FESCUE TANKS

Parameter	Tank 3. Fast Flow Rate					Tank 4. Slow Flow Rate				
	Winter	Spring	Summer	Fall	Annual Weighted Mean	Winter	Spring	Summer	Fall	Annual Weighted Mean
pH, units (range)	6.7-7.5	6.5-7.5	7.0-7.5	7.0-7.4	6.5-7.5	6.6-7.8	6.9-7.4	7.1-7.7	7.0-7.4	6.6-7.8
Electrical Conductivity (EC), micromhos/cm	1020	1084	1016	1097	1047	999	1117	995	1050	1029
Chemical Oxygen Demand (COD), mg/l	29.9	31.5	32.7	26.8	30.1	30.1	32.3	35.4	25.4	30.8
Biochemical Oxygen Demand (BOD), mg/l	4.2	3.9	4.2	4.6	4.3	2.6	4.7	4.1	4.4	4.0
Total Organic Carbon (TOC), mg/l	12.6	16.0	12.2	10.1	12.4	11.5	15.8	11.9	9.9	11.9
Total Phosphorus (T-P), mg/l as P	8.3	7.5	7.2	8.3	7.8	7.9	7.2	6.8	7.7	7.4
Organic Nitrogen (Org-N), mg/l as N	0.9	1.2	1.0	0.8	1.0	1.2	1.4	1.3	0.7	1.1
Ammonia Nitrogen (NH_3-N), mg/l as N	3.7	3.2	0.7	0.9	2.1	2.6	2.4	0.8	0.6	1.6
Nitrite Nitrogen (NO_2-N), mg/l as N	<0.1	<0.1	<0.05	<0.05	<0.1	<0.1	<0.1	<0.05	<0.05	<0.1
Nitrate Nitrogen (NO_3-N), mg/l as N	2.9	1.2	0.3	1.0	1.4	2.4	0.5	0.1	0.4	0.9
Total Nitrogen (T-N), mg/l as N	7.3	5.7	2.0	2.7	4.5	6.1	4.0	2.1	1.6	3.5
Chloride (Cl), mg/l	88	92	97	120	102	91	107	92	112	100
Sulfate (SO_4), mg/l	52	64	41	42	45	45	56	31	40	39
Calcium (Ca), mg/l	79	98	84	77	82	78	101	83	82	83
Magnesium (Mg), mg/l	35	30	30	37	34	33	30	30	38	33
Potassium (K), mg/l	6.1	6.3	6.6	6.5	6.3	5.0	5.4	6.9	5.6	5.6
Sodium (Na), mg/l	91	82	96	105	94	91	89	94	107	95

Note: Milligrams per liter multiplied by 8.34×10^{-3} equals pounds per 1000 gallons.

TABLE 5

MEAN CHARACTERISTICS OF EFFLUENT FROM THE PERENNIAL RYEGRASS TANKS

Parameter	Tank 5. Fast Flow Rate					Tank 6. Slow Flow Rate				
	Winter	Spring	Summer	Fall	Annual Weighted Mean	Winter	Spring	Summer	Fall	Annual Weighted Mean
pH, units (range)	6.7-7.5	6.5-7.8	7.1-7.6	7.2-7.5	6.5-7.8	6.7-7.9	6.9-7.6	7.2-7.7	7.1-7.7	6.7-7.9
Electrical Conductivity (EC), micromhos/cm	1015	1096	1032	1103	1055	999	1117	967	1042	1018
Chemical Oxygen Demand (COD), mg/l	31.8	32.6	33.1	29.5	31.7	29.2	32.6	33.3	25.5	30.0
Biochemical Oxygen Demand (BOD), mg/l	4.1	3.9	2.5	4.8	3.8	3.5	4.6	4.0	4.0	4.0
Total Organic Carbon (TOC), mg/l	14.2	15.2	11.2	10.9	12.7	11.1	13.8	12.9	10.7	11.9
Total Phosphorus (T-P), mg/l as P	8.2	7.7	7.4	8.5	8.0	7.7	6.9	6.4	8.2	7.3
Organic Nitrogen (Org-N), mg/l as N	1.4	1.2	1.1	1.2	1.2	1.0	1.5	1.0	0.7	1.0
Ammonia Nitrogen (NH_3-N), mg/l as N	3.8	2.9	0.6	1.1	2.1	2.7	1.9	0.5	0.6	2.7
Nitrite Nitrogen (NO_2-N), mg/l as N	<0.1	<0.1	<0.05	<0.05	<0.1	<0.1	<0.05	<0.05	<0.05	<0.1
Nitrate Nitrogen (NO_3-N), mg/l as N	3.2	1.3	0.8	1.7	1.8	2.4	0.6	0.1	1.4	1.2
Total Nitrogen (T-N), mg/l as N	8.3	5.4	2.5	3.9	5.1	6.1	4.1	1.6	2.7	3.7
Chloride (Cl), mg/l	80	104	106	128	107	81	104	91	110	96
Sulfate (SO_4), mg/l	49	69	43	43	46	44	64	40	44	44
Calcium (Ca), mg/l	77	96	81	77	80	79	100	83	74	82
Magnesium (Mg), mg/l	34	29	29	38	33	33	29	30	39	33
Potassium (K), mg/l	7.6	6.8	7.6	8.3	7.6	7.0	6.0	7.4	6.9	6.9
Sodium (Na), mg/l	85	96	100	111	95	84	87	96	99	90

Note: Milligrams per liter multiplied by 8.34×10^{-3} equals pounds per 1000 gallons.

TABLE 6

MEAN REMOVAL PERCENTAGES FOR TOTAL NITROGEN, COD, AND BOD
(CONCENTRATION BASIS)

Season	Control		Fescue		Ryegrass	
	Fast Rate	Slow Rate	Fast Rate	Slow Rate	Fast Rate	Slow Rate
			Total Nitrogen			
Winter	47.9	52.3	65.5	72.4	58.5	72.4
Spring	34.0	42.6	50.6	65.2	53.7	64.1
Summer	72.8	85.1	82.8	84.6	78.2	89.2
Fall	64.4	69.6	83.0	89.5	75.5	83.2
			COD			
Winter	62.8	57.6	64.4	63.9	61.4	67.1
Spring	41.7	39.2	47.5	51.0	47.7	48.4
Summer	43.8	39.1	42.7	38.1	43.3	41.6
Fall	53.1	52.4	51.4	53.5	45.7	53.3
			BOD			
Winter	84.4	----	88.4	91.0	89.7	90.5
Spring	84.2	77.4	86 1	84.7	84.3	83.8
Summer	89.1	87.4	85.5	85.7	90.3	83.8
Fall	84.3	87.1	82.1	83.4	83.8	85.9

percentages for total nitrogen (T-N), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) are summarized in Table 6. The values reported are seasonal means for each of the six tanks. These data show that the control tanks were, in fact, quite effective in reducing the organic and nitrogen content of the sewage effluent supplied. Statistical techniques were employed to evaluate the effects of the grasses, flow rates, and seasons on treatment efficiencies.

Nitrogen removal. Factorial analysis of variance was used to determine the significance of grass species, flow rate, and season on total nitrogen reduction. Both fescue and ryegrass were significantly better than the control at the 5 percent level of confidence. There was no significant

difference in the nitrogen removal by the fescue and ryegrass tanks. Nitrogen removal in the slow flow rate tanks was significantly better than in the fast flow rate tanks. Summer performance was significantly better than winter and spring but not different from fall at the 5 percent confidence level. Likewise, fall performance was better than spring and winter. There was no significant difference between winter and spring in nitrogen removal. In summary, it was shown that grasses, flow rate, and seasons all had significant effects on total nitrogen reduction in the hydroponic tanks.

COD removal. The greatest reduction of COD in the hydroponic tanks occurred during the winter seasons, followed by fall, spring, and summer in descending order. Factorial analysis of variance revealed winter removal of COD to be significantly better than spring and summer at the 5 percent confidence level, but not significantly greater than fall removals. There was no significant difference between the performance of spring and summer, spring and fall, nor between summer and fall. The analysis also showed no significant effect could be attributed to flow rate nor grasses. The latter indicated no significant differences between the control tanks and grass tanks in COD reduction.

BOD removal. The data of Table 6 show that there was no consistent and predictable trend associated with BOD removals. Factorial analysis of variance of the data verified this obvious conclusion. It did, in fact, show that there was no significant change in BOD removal due to grasses (versus controls), flow rate of effluent, nor season of operation. Of all the parameters examined, BOD removal was the most consistent. Simply flowing the effluent through the flooded gravel bed was quite effective in reducing the BOD content of the sewage effluent.

Total phosphorus. One of the principal objectives of this study was to evaluate the removal efficiencies of the hydroponic tanks for the nutrient compounds of nitrogen and phosphorus. As previously shown, significant nitrogen removals were obtained. This was not the case for the total phosphorus content of the sewage effluent. Reductions were so small and erratic that percent removals were not used to evaluate the data. In many cases, individual weekly samples showed equal or slightly greater phosphorus content than that of the effluent supplied to the tanks. This also is evident in some of the mean seasonal data summarized in Table 7.

The concentration data were analyzed using a factorial analysis of variance. The analysis showed no significant change in phosphorus concentration due to grass versus control. The most consistent effect was noted between flow rates. Concentrations from the slow flow rate tanks were significantly lower at the 5 percent confidence level than those from the fast flow tanks. Likewise, significant seasonal effects were noted when comparisons between inflow and outflow were made. The overall mean values of Table 7 show the rank of the seasons and how these compared with the mean values for the sewage effluent supplied to the hydroponic tanks. The data indicate that both biological fixation and release occurred in the tanks. The only phosphorus actually removed from the system was that which was utilized by the grasses. Apparently, this was a small amount in comparison to the quantity supplied to the tanks.

TABLE 7

MEAN TOTAL PHOSPHORUS CONCENTRATIONS IN SEWAGE EFFLUENT AND EFFLUENTS FROM THE HYDROPONIC TANKS, mg/l

Source	Winter	Spring	Summer	Fall	Annual
Sewage Effluent	9.5	7.6	7.3	8.6	8.1
1. Control Fast Flow Rate	8.8	7.4	7.3	8.6	8.1
2. Control Slow Flow Rate	8.7	7.8	6.2	8.0	7.7
3. Fescue Fast Flow Rate	8.3	7.5	7.2	8.3	7.8
4. Fescue Slow Flow Rate	7.9	7.2	6.8	7.7	7.4
5. Ryegrass Fast Flow Rate	8.2	7.7	7.4	8.5	8.0
6. Ryegrass Slow Flow Rate	7.7	6.9	6.4	8.2	7.3
Overall Mean (outflow)	8.4	7.4	6.7	8.2	

Grass Yields and Quality

The grasses were harvested eight times during the year. Moisture content and dry weight yield data are summarized in Table 8. For easy conversion to pounds or tons per acre, yield samples were cut from an area of 9.6 square feet. The yield in grams from that area multiplied by 10 gave pounds per acre. Moisture content was determined by drying the freshly cut samples in a 65°C oven. Samples of the dried grasses were retained for chemical analysis.

Considerable differences in yield were noted between the inlet and outlet ends of the tanks at some of the harvests. The values reported in Table 8 are averages for the entire tank length. In some cases, as many as four yield samples were taken from each tank. Never were less than two samples taken to represent the harvest from each tank. This difference in yield

TABLE 8

MOISTURE CONTENT AND DRY WEIGHT YIELD OF THE GRASSES

Harvest Date	Kentucky Fescue				Perennial Ryegrass			
	Fast Flow Rate		Slow Flow Rate		Fast Flow Rate		Slow Flow Rate	
	Moisture Content	Dry Weight Yield	Moisture Content	Dry Weight Yield	Moisture Content	Dry Weight Yield	Moisture Content	Dry Weight Yield
	percent	tons/acre	percent	tons/acre	percent	tons/acre	percent	tons/acre
1/5/68	78.2	1.69	76.1	1.70	79.3	0.90	76.9	0.55
3/29/68	83.8	1.32	84.9	1.78	86.5	1.52	86.2	1.24
4/30/68	84.7	1.87	85.3	2.40	85.8	2.62	85.0	2.67
6/3/68	82.4	1.39	81.4	1.16	81.2	1.06	78.2	0.70
7/1/68	80.8	0.79	77.7	0.52	73.2	0.31	72.7	0.17
8/7/68	77.2	0.91	74.6	0.70	----	----	----	----
9/27/68	81.6	1.04	79.4	0.70	80.8	0.17	76.9	0.15
11/19/68	79.8	1.58	76.8	1.09	74.4	0.59	72.8	0.45
Total Yield	----	10.59	----	10.05	----	7.17	----	5.93

could only be attributed to the reduction of nitrogen as the effluent flowed slowly through the tanks. This observation raises the question of optimum tank length which was not answered by this study.

The effect of seasons on yield is evident from the data of Table 8. The greatest 30-day yields were obtained during the month of April. The summer months of July and August produced the least yields. After producing seed, the ryegrass remained practically dormant until new fall growth began. The fescue continued to grow during the summer but at a greatly reduced rate. Other grasses should be studied to find those which give the best growth during all seasons. Reed canarygrass is one that looks promising and should be grown under hydroponic conditions for evaluation.

The dried grass samples were analyzed for crude protein, phosphorus, potassium, calcium, and sodium (Table 9). Nitrogen content was obtained by a conversion factor from crude protein content. Nitrogen in the nitrate form was not detectable in any of the samples. This analysis should probably have been attempted on fresh plant material rather than the dried samples. Crude protein, nitrogen, and phosphorus content all varied according to stage of plant growth. The most active growing periods gave the highest values for each of these. Potassium did not show as much variation in the fescue as it did in the ryegrass. Nitrogen content was consistently 3 to 4 times that of phosphorus in all samples. The crude protein content during the most active growing periods was sufficiently high to class these grasses as having high nutritive value.[1] The slow growth period of mid-summer produced the lowest grass quality. With each grass, this occurred after seed production and before fall growth started.

Nutrients Removed by Harvest

From yield and quality data (Tables 8 and 9) the total nutrients (N, P, and K) removed by grass harvests are shown in Table 10. These values are reported in pounds per acre. (To convert to pounds removed by each hydroponic tank, divide by 760.) In order to establish a nutrient balance for the hydroponic system, estimates of the major nutrients leaving the hydroponic tanks in the outflow were made from the annual mean values of Tables 3, 4, and 5. An allowance for an average of 3 percent reduction in flow due to evapotranspiration was made and the results are shown in Table 11. The period covered by grass harvests was about 60 weeks.

Combining data from Tables 2, 10, and 11, a balance of nutrients, N, P, and K, was made. The fate of nutrients accounted for during the 60-week period is shown in Table 12. These data indicate the difficulty encountered in attempting a nitrogen balance. Much of the nitrogen that was unaccounted for probably was lost through the processes of denitrification which

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[1]Stidham, Neal, Area Range Specialist, Soil Conservation Service, Ada, Oklahoma, personal communication, February 1969.

TABLE 9

ANALYSES OF GRASS SAMPLES*

Harvest Date	Percent, dry weight basis					
	Crude Protein	Nitrogen	Phosphorus	Potassium	Calcium	Sodium
Fescue:						
1/5/68	17.1	1.71	0.57	2.8	0.13	0.19
3/29/68	21.0	2.10	0.56	2.9	0.12	0.19
4/30/68	19.0	1.90	0.56	2.6	0.12	0.29
6/3/68	13.0	1.30	0.40	2.4	0.11	0.11
7/1/68	11.0	1.10	0.39	2.3	0.17	0.19
8/7/68	10.1	1.01	0.37	2.0	0.12	0.17
9/27/68	13.3	1.33	0.41	2.3	0.11	0.16
11/19/68	14.3	1.43	0.48	2.8	0.12	0.19
Ryegrass:						
1/5/68	23.3	2.33	0.54	2.1	0.12	0.45
3/29/68	20.2	2.02	0.57	3.0	0.14	0.49
4/30/68	13.2	1.32	0.46	1.8	0.12	0.72
6/3/68	8.3	0.83	0.38	1.7	0.15	0.41
7/1/68	12.5	1.25	0.39	0.93	0.20	0.52
9/27/68	14.3	1.43	0.37	1.2	0.13	0.32
11/19/68	15.6	1.56	0.46	1.9	0.12	0.32

*The grass analyses were performed by The Samuel Roberts Noble Foundation, Inc., Ardmore, Oklahoma.

TABLE 10

PLANT NUTRIENTS REMOVED BY THE GRASS HARVESTS, POUNDS PER ACRE

Harvest Date	Fast Flow Rate			Slow Flow Rate		
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Fescue:						
1/5/68	57.78	19.26	94.64	58.14	19.38	95.20
3/27/68	55.44	14.78	76.56	74.76	19.92	103.24
4/30/68	71.06	20.94	97.24	91.20	26.88	124.80
6/3/68	36.14	11.12	66.72	30.16	9.28	55.68
7/1/68	17.38	6.16	36.34	11.44	4.04	23.92
8/7/68	18.38	6.72	36.40	14.14	5.18	28.00
9/27/68	27.66	8.52	47.84	18.62	5.74	32.20
11/19/68	45.18	15.16	88.48	31.16	10.46	61.04
Total	329.02	102.66	544.22	329.62	100.88	524.08
Ryegrass:						
1/5/68	41.94	9.72	37.80	25.62	5.94	23.10
3/29/68	61.40	17.32	91.20	50.08	14.12	74.40
4/30/68	69.16	24.10	94.32	70.48	24.56	96.12
6/3/68	17.58	8.04	36.04	11.62	5.32	23.80
7/1/68	7.74	2.40	5.76	4.24	1.32	3.16
9/27/68	4.86	1.24	4.08	4.28	1.10	3.60
11/19/68	18.40	5.42	22.42	14.04	4.14	17.10
Total	221.08	68.24	291.62	180.36	56.50	241.28

Note: To convert these values to pounds removed per hydroponic tank, divide by 760.

TABLE 11

PLANT NUTRIENTS LEAVING THE HYDROPONIC TANKS, POUNDS PER ACRE
(BASED ON OUTFLOW FOR 60 WEEKS)

Nutrient		Fast Flow Rate		Slow Flow Rate	
		lb/ac/wk	lb/acre	lb/ac/wk	lb/acre
Control:					
Nitrogen	(N)	63.84	3830.4	26.60	1596.0
Phosphorus	(P)	73.72	4423.2	34.96	2097.6
Potassium	(K)	73.72	4423.2	32.68	1960.8
Fescue:					
Nitrogen	(N)	31.92	1915.2	15.20	912.0
Phosphorus	(P)	66.88	4012.8	32.68	1960.8
Potassium	(K)	50.16	3009.6	25.08	1504.8
Ryegrass:					
Nitrogen	(N)	32.68	1960.8	15.96	957.6
Phosphorus	(P)	66.12	3967.2	32.68	1960.8
Potassium	(K)	62.32	3739.2	31.16	1869.6

Note: Pounds per acre divided by 760 equals pounds per hydroponic tank.

occurred in the anaerobic environment of the flooded gravel bed. The oxygen-demanding nature of the waste must have kept the oxygen depleted at all except a shallow surface layer, thus promoting denitrification throughout most of the tank volume. Upon examination of the root systems developed by the grasses, it was found that most of the roots were within the top six to eight inches of the gravel bed. This further indicated the anaerobic conditions which existed within the lower portion of the gravel bed.

The data of Table 12 reveal that greater percentages of the nutrients supplied were removed by grass harvests from the slow flow rate tanks of both grasses. This is in contrast to the yield data of Table 8, which shows that the fast flow rate tanks gave the higher yield with both grasses. The higher yield of fescue over ryegrass is also reflected in the greater percentages of nutrients removed by harvest.

The data of Table 12 show that the grasses were, in fact, minor contributors to nutrient removal from the waste when compared to the total quantity of nutrients that passed through the tanks and returned to the stream flow. Much of the phosphorus and potassium unaccounted for was no doubt retained in the root systems and aerial growth that was not harvested. In addition, considerable biological slime growth developed within the gravel bed.

TABLE 12

FATE OF NITROGEN, PHOSPHORUS, AND POTASSIUM SUPPLIED TO THE HYDROPONIC TANKS DURING 60-WEEK PERIOD

Nutrient	Fast Flow Rate							Slow Flow Rate						
	Supplied to tank	Leaving tank in outflow		Removed by grass harvest		Unaccounted for		Supplied to tank	Leaving tank in outflow		Removed by grass harvest		Unaccounted for	
	pounds	pounds	percent	pounds	percent	pounds	percent	pounds	pounds	percent	pounds	percent	pounds	percent
Control:														
Nitrogen (N)	11.40	5.04	44.2	----	----	6.36	55.8	5.70	2.10	42.8	----	----	3.60	63.2
Phosphorus (P)	6.00	5.82	97.0	----	----	0.18	3.0	3.00	2.76	92.0	----	----	0.24	8.0
Potassium (K)	6.36	5.82	91.5	----	----	0.54	8.5	3.18	2.58	81.1	----	----	0.60	18.9
Fescue														
Nitrogen (N)	11.40	2.52	22.1	0.43	3.8	8.45	74.1	5.70	1.20	21.1	0.43	7.6	4.07	71.3
Phosphorus (P)	6.00	5.28	87.9	0.14	2.3	0.58	9.8	3.00	2.58	86.0	0.15	4.4	0.29	9.6
Potassium (K)	6.36	3.96	62.2	0.72	11.3	1.68	26.5	3.18	1.98	62.2	0.69	21.7	0.51	16.1
Ryegrass:														
Nitrogen (N)	11.40	2.58	22.6	0.29	2.6	8.53	74.8	5.70	1.26	22.1	0.24	4.2	4.20	73.7
Phosphorus (P)	6.00	5.22	87.0	0.09	1.5	0.69	11.5	3.00	2.58	86.0	0.07	2.5	0.35	11.5
Potassium (K)	6.36	4.92	77.4	0.38	6.0	1.06	16.6	3.18	2.46	77.3	0.32	10.0	0.40	12.7

Note: Pounds per hydroponic tank multiplied by 760 equals pounds per acre.

Nutrients thus retained are not accounted for in the data of Table 12. This black slime growth developed around the inlet manifold to the extent that flow was retarded at times during the latter months of the study. Periodically draining the tanks to permit aeration assisted in restoring normal flow through the tanks.

Bacterial Reductions

Bacterial counts were made periodically on both inflow and outflow samples during the study. Total counts were expressed as number of organisms per 100 ml sample. The data are summarized in Table 13. The values are means for monthly periods and the percent reductions are means for all six tanks. Individual data showed no consistent differences in the bacterial reductions of any of the tanks. The only apparent effect was one of seasons as shown in Table 13. The bacterial reductions during February were somewhat less than those of the other months reported. No real significance can be attached to this variability, since all seasons of the year were not represented in the data.

TABLE 13

MEAN BACTERIAL COUNTS AND PERCENT REDUCTIONS AFTER FLOW THROUGH THE HYDROPONIC TANKS

Date	Total Coliforms (Inflow)	Percent Reduction	Fecal Coliforms (Inflow)	Percent Reduction	Fecal Streptococci (Inflow)	Percent Reduction
September 1967	1.4×10^6	99.0	2.4×10^5	99.6	2.1×10^4	99.4
November 1967	2.4×10^6	96.8	3.6×10^5	94.5	6.7×10^4	94.5
February 1968	1.9×10^6	81.9	6.2×10^5	88.0	1.7×10^5	88.3
April 1968	1.2×10^6	94.8	3.1×10^5	95.9	4.6×10^4	95.7

Note: (1) Total bacterial counts are expressed as number of organisms per 100 ml.

(2) Percent reductions are mean values for all six tanks.

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27 Abstract

Grasses were grown in hydroponic culture tanks to evaluate their nutrient removal capabilities when supplied with secondary-treated sewage effluent as the sole source of plant nutrients. Statistical methods were employed to determine the effects of the grasses, flow rates, and seasons on nutrient removal.

Two control tanks with gravel bed and no grass were maintained throughout the study, two were planted with tall (Ky 31) fescue, and two were planted with perennial ryegrass. Two flow rates were maintained in each pair of tanks, approximately one-day and two-day detention times. All six tanks were effective in reducing the oxygen-demanding organic content of the effluent. Total nitrogen content was reduced appreciably by the control tanks, but the grass tanks were significantly better at nitrogen removal. Total phosphorus concentrations were reduced only slightly by passage through the tanks. The fast flow rate tanks produced the greater grass yields, while the slow flow rate tanks were more effective in nutrient removal from the sewage effluent.

From grass yield and analyses data, the amount of plant nutrient material removed by the grasses was small compared to the total quantity supplied. Further studies are suggested to determine economic factors and design parameters.

Abstractor: James P. Law, Jr.

Institution: Robert S. Kerr Water Research Center, SCR
~~FWQA, USDI~~

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